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How the Sima de los Huesos was won

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Abstract

Although the first discovery of a human fossil in the Sima de los Huesos took place in 1976, systematic excavations did not begin there until 1984. Since then, this site has been continuously excavated in month-long camps. The site is dated by different radiometric techniques to between 430,000 and 300,000 years ago. Until the 2023 campaign, just over 7000 human fossils have been recovered, constituting the largest collection of fossils prior to *Homo sapiens* ever discovered. The fossils correspond to a minimum of 29 individuals of both sexes and different ages at death, from preadolescents to a specimen of advanced age. Comparative anatomy and ancient DNA studies both suggest that this is a population closely related to *Homo neanderthalensis*. The great variety and extraordinary quality of the fossils recovered have allowed us to carry out a series of investigations that have greatly increased our knowledge

about the evolution of *Homo* in the Middle Pleistocene. Among the most important discoveries, it has been possible to establish body size and proportions, the confirmation that the origin of the accumulation of human fossils was of an anthropic nature, that those past humans took care of disabled individuals and who were capable of having an oral language almost as complex and efficient as that of our own species.

KEYWORDS

Atapuerca, history of the discoveries, homo, human evolution, middle Pleistocene

1 | INTRODUCTION

The Sima de los Huesos (SH) is a truly unusual site in the panorama of world Paleoanthropology (Arsuaga, 2024, this volume). Today, it is the place on the planet where more Pleistocene human fossils have been recovered (more than 7000) than any other site, corresponding to a minimum of 29 individuals of both sexes and different ages at death (Martínez et al., 2024, this volume), from a small child to an elderly individual. The state of preservation of the fossils is so extraordinary that it has allowed the feat of recovering and sequencing DNA, mitochondrial and nuclear, from around 430,000 years ago. All this has allowed us to carry out a long series of studies that have greatly expanded our knowledge of human evolution, especially during the Middle Pleistocene of Europe. We now know that SH humans were evolutionarily in the lineage of later Neanderthals, that their statures were similar to those of many modern human populations, but that their bodies were much wider, which resulted in a greater body weight (Arsuaga et al., 1999, 2015). We have also discovered that their degree of sexual dimorphism in body size was similar to that of our own species (Arsuaga, Carretero, et al., 1997), that their communicative abilities were more similar to those of modern humans than to those of chimpanzees (Martínez et al., 2004, 2013), that they cared for the vulnerable (Gracia et al., 2009), and that they provided a final resting place for their deceased (Sala et al., 2015). All this new information has substantially changed the view in the last quarter of the 20th century of the prehistoric mankind. We now know that those prehistoric humans were very human, much more so than most researchers imagined.

All this being of great importance, the Sima de los Huesos has another feature that makes it especially unique. It is probably the only site in the history of Paleoanthropology that has been excavated systematically and uninterruptedly for the last 40 years by the same team of people. The history of the excavations in the Sima de los Huesos is, in itself, a fascinating story developed in a small cavity, with an atmosphere rarefied by the abundant carbon dioxide, located at the foot of a 12-m drop chasm which is located more than 700 m from the present entrance to the Cueva Mayor of the Sierra de Atapuerca. The story of the excavations and research carried out in the Sima de los Huesos is an exciting succession of amazing scientific discoveries, but it is also a story of overcoming difficulties, perseverance, illusions, defeats, and successes over four decades, all lived as a team. Fortunately, the excavation of the Sima de los Huesos has had an exceptional witness throughout this time: the film camera, which has kept the memory of the stellar moments that have occurred in this hidden place in the geography of Burgos. Having the fortune of hundreds of hours of recordings, made over more than three decades, we decided to write a unique article on the history of the excavations in the Sima de los Huesos in which a really historic video is used to document it Video 1 (Supplementary Material).

1.1 | Once upon a time in Atapuerca (1976–1983)

The Sierra de Atapuerca is located 12 km east of the city of Burgos, in northern Spain and consists of a modest flat-topped anticline formed by limestone rocks (Figure 1), whose sediments were deposited at the end of the Cretaceous period between 70 and 65 million years ago (Ma). On its western slopes is the largest set of Pleistocene sites in Europe and one of the largest in the world. Over the last million and a half years, groundwater erosion created a complex karst system, many of whose cavities were opened to the outside world and gradually filled with sediments. This process gave rise to the present-day prehistoric sites in the Sierra de Atapuerca (Figure 2).

Between 1896 and 1900, a small mining railroad was built, and its route cut through some of the cavities filled with sediments, exposing some of the most important Atapuerca sites located in the area known as the Trinchera del Ferrocarril (Railway Trench). In one of these sites,

VIDEO 1 Original images of the main discoveries in the Sima de los Huesos and interviews to the researchers. Video content can be viewed at https://onlinelibrary.wiley.com/doi/10.1002/ar.25509

FIGURE 1 General view of Sierra de Atapuerca from the southwest.

the Gran Dolina, a group of human fossils more than 800,000 years old were discovered in 1994 (Figure 3). At that time, they represented the oldest human fossils on the European continent and were assigned to a new species: *Homo antecessor*, which is the closest known to the last common ancestor of the Neanderthal and *Homo sapiens* lineages (Bermúdez de Castro et al., 1997). Thirteen years later, two even older human fossils (a mandibular fragment and a foot phalanx) were found at the nearby Sima del Elefante site (Figure 4), also in the Trinchera del Ferrocarril (Carbonell et al., 2008). They are estimated to be about 1.2 Ma old and are the oldest known human fossils on the European continent.

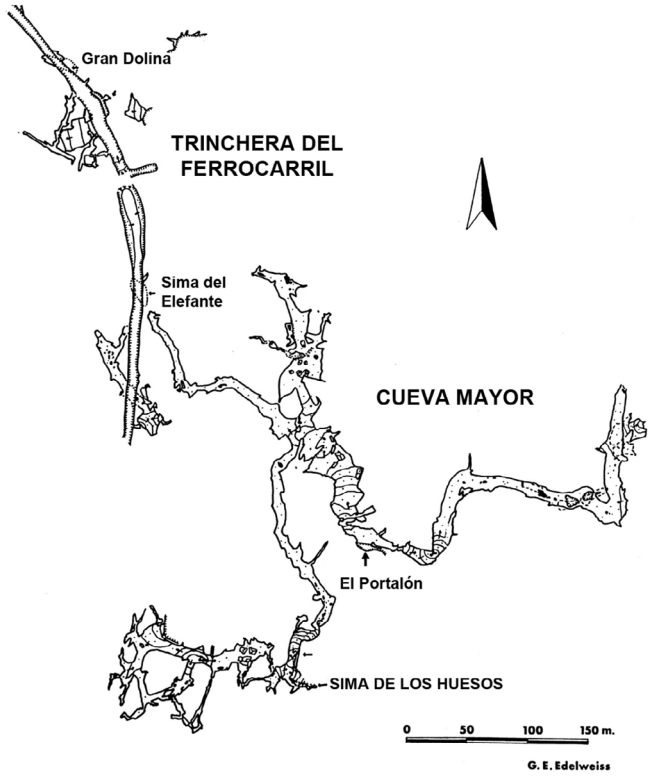

FIGURE 2 Map of the location of the main sites in the Sierra de Atapuerca.

Only 300 m from the Sima del Elefante, as the crow flies, is the entrance to the Cueva Mayor (Figure 5), a large room called the Portalón. The Cueva Mayor has been known among prehistoric professionals since 1910, when the archeologist Jesús Carballo revealed the existence of a painting representing the left profile of a horse's head in red. Some of the most prestigious researchers of that time, such as Hugo Obermaier and Henri Breuil, catalogued the painting as belonging to the

FIGURE 4 Mandible of *Homo* sp. recovered in 2006 in level TE9 of the Sima del Elefante.

FIGURE 3 All anatomical regions of at least 11 individuals are represented in the *Homo antecessor* fossils recovered at TD6.

FIGURE 5 Current entrance to the Cueva Mayor.

FIGURE 6 Excavation in the Holocene levels of the El Portalón site. José Miguel Carretero in the center of the photo.

FIGURE 7 Juan Luis Arsuaga descending to the Sima de los Huesos site through a 13-m chasm.

Paleolithic period. This discovery led to a series of excavations in the Portalón, including one conducted by José María Apellániz between 1973 and 1983, which uncovered an important Bronze Age site (Arsuaga, Martínez, et al., 1997). Excavations were resumed in 2000 by the current team led by Juan Luis Arsuaga and have continued uninterruptedly until the present day, uncovering a long sequence that includes the Chalcolithic and Neolithic periods (Figure 6).

In 1976, members of the Edelwiss Speleology Group of the Burgos Provincial Council informed a young researcher, Trinidad de Torres, who was looking for fossil bear remains for his doctoral thesis, that in a small cave, located at the foot of a chasm (Figure 7) with a drop of about 13 m and more than 700 m from the Portalón, there was a place called the Sima de los Huesos (Figure 8) that contained hundreds of bear remains. Torres decided to carry out a short excavation campaign there and so he sent four speleologists to the Sima de los Huesos who found, among hundreds of bear fragments, a very complete human jawbone (Figure 9). Torres was immediately aware of the importance of the discovery and took the piece to his thesis director, Emiliano Aguirre, a true expert in human evolution (Figure 10). Aguirre confirmed the importance of the find, as it was a fossil whose morphology was even more primitive than that of the Neanderthals. On the other hand, the association of the human fossil with fossil remains of bear species (*Ursus deningeri*) that had become extinct at the end

FIGURE 8 View of the Sima de los Huesos site in the 1995 field season. In the foreground, Carlos Lorenzo. In the background, José Miguel Carretero, on the left, Juan Luis Arsuaga, in the center, and Alfonso Esquivel, on the right.

FIGURE 9 AT-1 mandible. This specimen was the first human fossil recovered in the Sima de los Huesos in 1976.

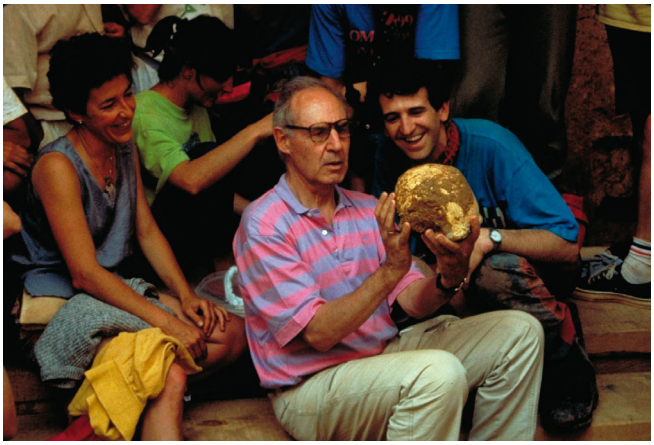

FIGURE 10 Emiliano Aguirre and Juan Luis Arsuaga admiring Cranium 4 the day it was extracted from the site.

of the Middle Pleistocene pointed to a great antiquity of the human jaw. When reviewing the rest of the material extracted from the Sima de los Huesos, new human fragments of jaw, cranium, tibia, humerus, and some teeth were found, up to a total of 20 pieces, which multiplied the importance of the finding. Encouraged by the discovery, Aguirre considered carrying out a systematic excavation of the Sima de los Huesos in search of new human remains. However, the peculiar characteristics of the site made excavation extremely difficult. In fact, the site was located at the bottom of a deep chasm at the end of a gallery, very far from the entrance, with some narrow passages that were difficult to access. In addition, the site's atmosphere is rarefied by a very high level of carbon dioxide and, what was worse, the site had been visited for decades by amateurs looking for bear teeth as trophies. As a result of their activities, the upper levels of the site had been disturbed and mixed over and over again, making it necessary to dislodge a large amount of sediments and limestone blocks from the site before reaching the undisturbed levels. The truth is that no other site in the world was known to have such difficult excavation conditions. For this reason, Aguirre decided to postpone the excavation of the Sima de los Huesos, while waiting for the material and human resources to undertake the enormous task and concentrated on beginning to excavate the deposits of the Trinchera del Ferrocarril. In the 1983 campaign, a short visit was made to the Sima de los Huesos with the purpose of collecting a sample of the disturbed sediments to verify the richness in human fossils of the site. The prospecting was successful, and a phalanx and three human teeth were found, confirming expectations about the scientific value of the site. And so, in 1984, 8 years after the discovery of the first human mandible in the Sima de los Huesos, Aguirre decided that the time had come to begin systematic excavations at the site.

1.2 | The phantom site (1984–1990)

The 1984 campaign was devoted to installing the necessary infrastructure for excavation, including electric lighting, and began with the evacuation of the mass of sediments and bone fragments stirred up by hikers. The material was loaded into speleological backpacks and transported by the excavators on an exhausting journey to the Portalón and from there to the banks of the neighboring Arlanzón River, where it was washed, sieved, and later triaged in search of small fragments of human fossils (Figure 11).

During seven excavation campaigns, from 1984 to 1990 (both inclusive) approximately 12 tons of sediment and blocks were removed from the bottom of the

FIGURE 11 Washing of the sediments extracted from the Sima de los Huesos during the 1989 campaign. From left to right: Juan Luis Arsuaga, Ignacio Martínez, José Miguel Carretero and Curro González.

FIGURE 12 Teeth recovered from the Sima de los Huesos.

FIGURE 13 Carlos Lorenzo studying some of the phalanges from the Sima de los Huesos.

Sima de los Huesos and 228 new human fossils were recovered. In addition to these specimens, another 161 fossils were recovered from the debris of the 1976 campaign, which were also extracted and conveniently processed. In total, 389 human fossils were collected. This was an extraordinary number that far exceeded the sum of the rest of the European human fossils from sites of the same age at the Sima de los Huesos. However, almost all these fossils were small fragments that did not provide much information, but there were two very interesting elements: teeth and phalanges.

With the dozens of teeth collected during that time period (Figure 12), it was soon established that the minimum number of individuals was 20. The fact that there were remains of so many individuals at a site was unusual in the human fossil record for the Sima de los Huesos period. On the other hand, the phalanges of the hands and feet are among the most fragile bones of the body and rarely appear in sites of a certain age; in fact, no phalanges were known from any European site of equivalent age. However, in the Sima de los Huesos, a staggering 60 human phalanges were recovered

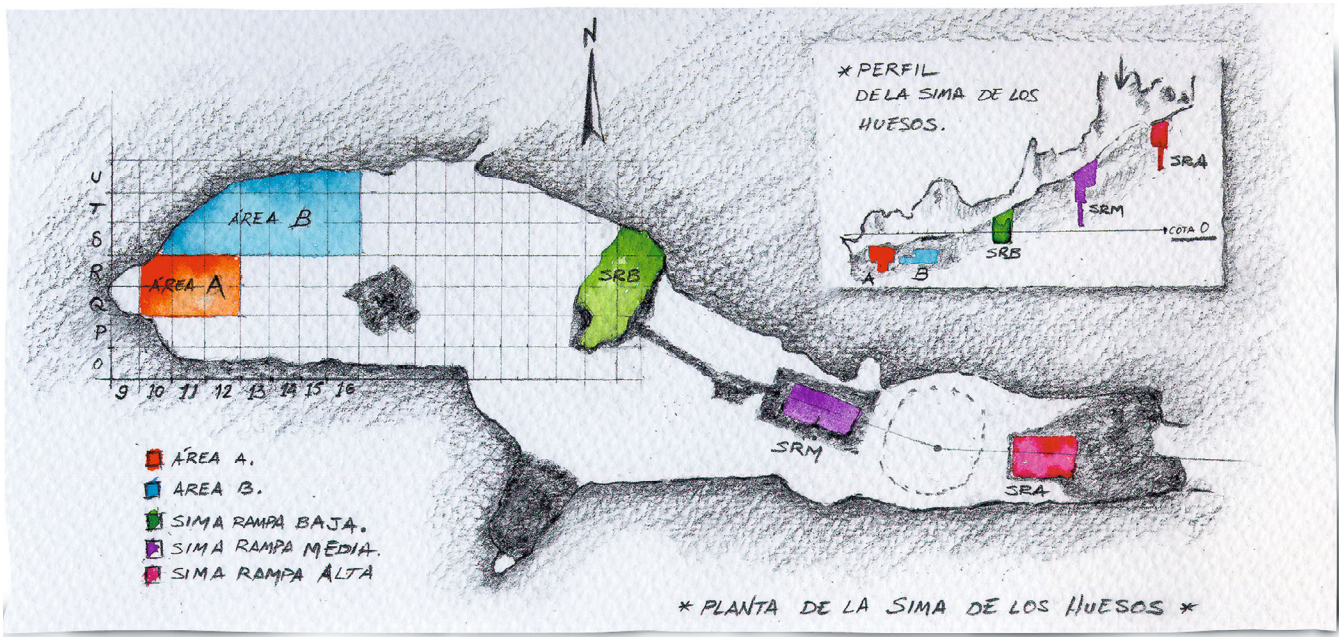

FIGURE 14 Diagram of the plan (main drawing) and section (in the inset) of the Sima de los Huesos site. The excavated areas are shown in different colors.

FIGURE 15 Ana Gracia during the process of reconstruction of the skulls of the Sima de los Huesos from hundreds of small fragments.

up to 1990 (Figure 13), which was an unequivocal sign to the research team that the original accumulation of human fossils in the Sima de los Huesos had consisted of complete skeletons, since it was not reasonable to think that it was precisely the most fragile bones of the skeleton that had been preserved, whereas other more resistant bones had been lost. The question was whether, after decades of uncontrolled excavations by amateurs, there was still any intact area of the original site.

In this sense, it was of great significance that in the 1984 campaign a small area at one corner of the Sima de los Huesos was cleared of disturbed sediments, which became known as *Area A*. This sector was systematically excavated in the last days of this campaign and yielded four human fossils recovered in an in-situ level, including an important fragment of a human mandible, which gave the researchers hope that a large part of the original site was still intact. *Area A* was excavated again the following year and again in 1989 and 1990, yielding 100 new human fossils. But in the 1990 excavation campaign, it seemed clear that *Area A* had been exhausted and that no more remains of the original site were left in the Sima de los Huesos. These were sad days for the team, as it seemed that the great effort made in the previous years was not going to be rewarded by success. But in the last days of the campaign, after finishing the evacuation of

FIGURE 16 Part of left maxillar and malar bones labeled AT-404. This cheekbone fragment was reconstructed from more than 20 small fragments recovered independently among the hundreds of small bone fragments recovered in the excavation. It was nicknamed by the researchers as *Lazarus*.

the last remains of disturbed sediment and clearing the site, six new human fossils were unexpectedly found, more complete than any other found up until that time, in another corner of the Sima de los Huesos, which was called *Area B* (Figure 14). This finding inspired hope that the level with human fossils extended over a much larger surface area than that represented by *Area A*.

Many of the hundreds of small fragments that were recovered corresponded to different regions of the cranium and the researchers began to try to put them together to reconstruct more complete parts (Figure 15). The task was especially complicated given the small size of the fragments and because at least 20 crania were represented in the collection (Pantoja-Pérez & Arsuaga, 2024, this volume). It was a matter of trying to reconstruct 20 puzzles of tiny pieces that had also been mixed together. The task required many hours of patient work in the laboratory, but little by little it was possible to assemble some fragments of three crania, which were called Cranium 1, 2, and 3 respectively. Perhaps, the most surprising, reconstructed piece was a fragment of the facial skeleton, from the region of the left cheekbone (Figure 16), which was reconstructed from more than 20 tiny fragments identified separately during the triage of the excavated material. This was the first fossil from the Sima de los Huesos to receive its own name and, given the miraculous nature of its reconstruction, it was nicknamed *Lazarus* after the young Jew resurrected by Jesus Christ.

A fundamental question, which especially intrigued the excavation team, was the age of the human fossils. Since they were found in altered sediments, it was not possible to determine the original stratigraphy of the site, which prevented the use of the standard dating techniques. Based on the comparative study of the morphology of the human fossils from the Sima de los Huesos with those of other fossils from sites of known age, the team members estimated that the minimum age of the Sima de los Huesos fossils was around 250,000 years and that their maximum age did not exceed 450,000 years. It would take many years to establish with certainty the age of the Sima de los Huesos fossils, which required the intervention of a large team of geochronologists.

The 1990 campaign was Aguirre's last, as he retired that same year. Over the years, since 1984, the team had been structured around three axes. One was led by Juan Luis Arsuaga, at the Complutense University of Madrid, who was mainly in charge of the systematic excavation of the Sima de los Huesos, the study of the geology of the sites and a large part of the research related to human fossils. A second team was organized around Eudald Carbonell, at the Rovira i Virgili University of Tarragona. This team was dedicated to the excavation of the sites of the Trinchera del Ferrocarril and was in charge of the study of the archeological aspects of the sites. Finally, at the National Museum of Natural Sciences in Madrid, Bermúdez de Castro led a team composed of specialists in human evolution, archeologists, and mammal paleontologists. After Aguirre's retirement, Arsuaga, Carbonell and Bermúdez de Castro collegially took over the leadership of the team, which was already known as the "Atapuerca Team" (Figure 17).

1.3 | The prodigious decade (1991–2000)

With this new structure, the team began the 1991 campaign. Determined to assess the extent of the human fossil level in the Sima de los Huesos, a quarter of a square meter excavation was carried out in the center of the Sima de los Huesos. After several days of excavation, in which only bear fossils were found, a human remains, a fenoral diaphysis, was finally discovered. It was established that the deposit of human fossils extended over a large part of the Sima de los Huesos, under a thick level

FIGURE 17 The Atapuerca Team at the end of the 1990 field season. 1: Emiliano Aguirre; 2: Juan Luis Arsuaga; 3: José María Bermúdez de Castro; 4: Eudald Carbonell.

containing only bear bones. Excavation over the next 3 weeks yielded 112 new human fossils of a size and state of preservation far superior to those from the disturbed sediments. Finally, the original level, from which the human fossils in the disturbed sediments were found, was uncovered and appeared richer than anyone had dared to imagine. But even the most optimistic members of the team were not prepared for what was to happen in the next excavation campaign.

A few days after excavation began in 1992, the edge of the supraorbital torus of a frontal bone appeared, standing out from the sediment surrounding the fossils. At first, the team members thought it was a new cranial fragment. Gradually, as the clay was removed, the bone became larger and larger, until it soon became clear that it was not a bone fragment, but an almost complete human cranium (Figure 18). Its scientific name is Cranium 4, but the team members nicknamed it *Agamemnon* in homage to classical archaeology (Figure 19). The find was of great importance, as at the time only three equivalent remains were known in Europe: The Swanscombe calvaria in England, the Petralona cranium in Greece, and the Steinheim cranium in Germany. The excavation of the cranium became more and more complicated because, before the astonished gaze of the team, as the excavation was extended, new and very complete human fossils appeared: a mandible, large fragments of long bones, coxal remains, teeth and, above all, a second disarticulated and fractured cranium, but with fragments still attached (Figure 20). The excavators named this new cranium (Cranium 5), which turned out to be even more complete than *Agamemnon*, *Miguelón* in honor of the Spanish cyclist Miguel Indurain (also nicknamed *Miguelón*), winner of five *Tours de France* and two *Giros d'Italia* from 1991 to 1995. In the excavations carried out since its discovery in 1992, its jaw and all the cervical vertebrae have been recovered. Thus, *Miguelón* is one of the best-preserved skulls in the world fossil record (Figure 21).

One of the most interesting aspects of the discovery of these crania was establishing the degree of variability to be expected in terms of cranial capacity in a Middle Pleistocene human population (Pantoja-Pérez & Arsuaga, 2024, this volume). In the European fossil record, there were crania with small cranial capacities, close to 1100 cc (such as the Steinheim case), whereas others were around 1300 cc (such as the Petralona cranium), which motivated

FIGURE 18 Ignacio Martínez excavating Cranium 4 in 1992. This skull was nicknamed *Agamennon* by researchers.

FIGURE 19 Cranium 4 from Sima de los Huesos. It was nicknamed by the researchers as *Agammenon*.

the discussion of whether such differences were due to sexual dimorphism in the same population or whether these differences had a taxonomic and phylogenetic value.

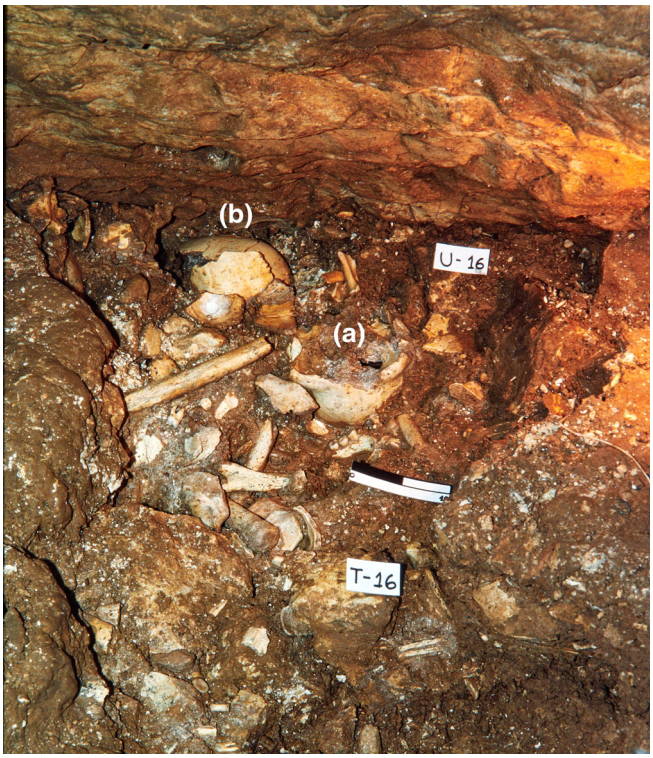

FIGURE 20 View of Area B of the Sima de los Huesos during its excavation in the 1992 field season. Cranium 4 (a) and Cranium 5 (b) can be seen surrounded by dozens of human fossils.

FIGURE 21 Lateral view of Cranium 5 with its mandible and all its cervical vertebrae. It was nicknamed by the researchers as *Miguelón*.

FIGURE 22 Frontal view of Cranium 6. It was nicknamed by the researchers as *Ruy*.

FIGURE 23 José Miguel Carretero shows the sacrum of Pelvis 1 during its excavation in 1994.

In this context, it was of great interest that while the cranial capacity of *Miguelón* was 1125 cc, that of *Agamemnon* reached 1390 cc. In other words, the Sima de los Huesos sample encompassed all the variation in cranial capacity of the European fossils of the Middle Pleistocene, which clearly indicated that these differences could reasonably be attributed to sexual dimorphism.

FIGURE 24 Pelvis 1 from Sima de los Huesos. It was nicknamed by the researchers as *Elvis*.

The excavation of the area needed to recover the two crania was only about a quarter of a square meter in size, but in such a small space, about 200 new high-quality human fossils were recovered. This was the largest accumulation of human fossils ever discovered from the European Middle Pleistocene ever discovered. Among them, were numerous cranium fragments, some of which could be connected in the laboratory with other cranial fragments from previous campaigns to compose a third cranium, this time from a specimen of about 12 years of age at death (Arsuaga et al., 1993). This third cranium (Cranium 6) received the affectionate name of *Ruy*, the family name by which the great Burgos hero of the Reconquest, Rodrigo Díaz de Vivar (better known as *El Cid Campeador*) was popularly known as a child (Figure 22).

But the extraordinary discoveries had only just begun. In 1994, another important discovery was made. Fragment by fragment, throughout the days, the team members rescued a set of bones that were in an extremely fragile state (Figure 23). It took all the team's expertise, acquired during a decade of work in the Sima de los Huesos, to extract and reconstruct what eventually turned out to be an almost complete human pelvis, inevitably nicknamed *Elvis* (Figure 24). It was a fossil of incalculable value because for a time interval of more than three million years, between the partial pelvis of *Lucy* and that of some Neanderthal specimen, no equivalent piece was known. The study carried out on *Elvis* made it possible to change a fundamental idea about human evolution that was generally accepted by the scientific community. Based on the reconstruction of the fragmentary pelvis of the KNM-WT-15000 skeleton, some authors proposed that *Homo erectus/ergaster* had the same narrow trunk body pattern as *H. sapiens* (Arsuaga et al., 1999). This was an idea that seemed very accurate, given the tropical

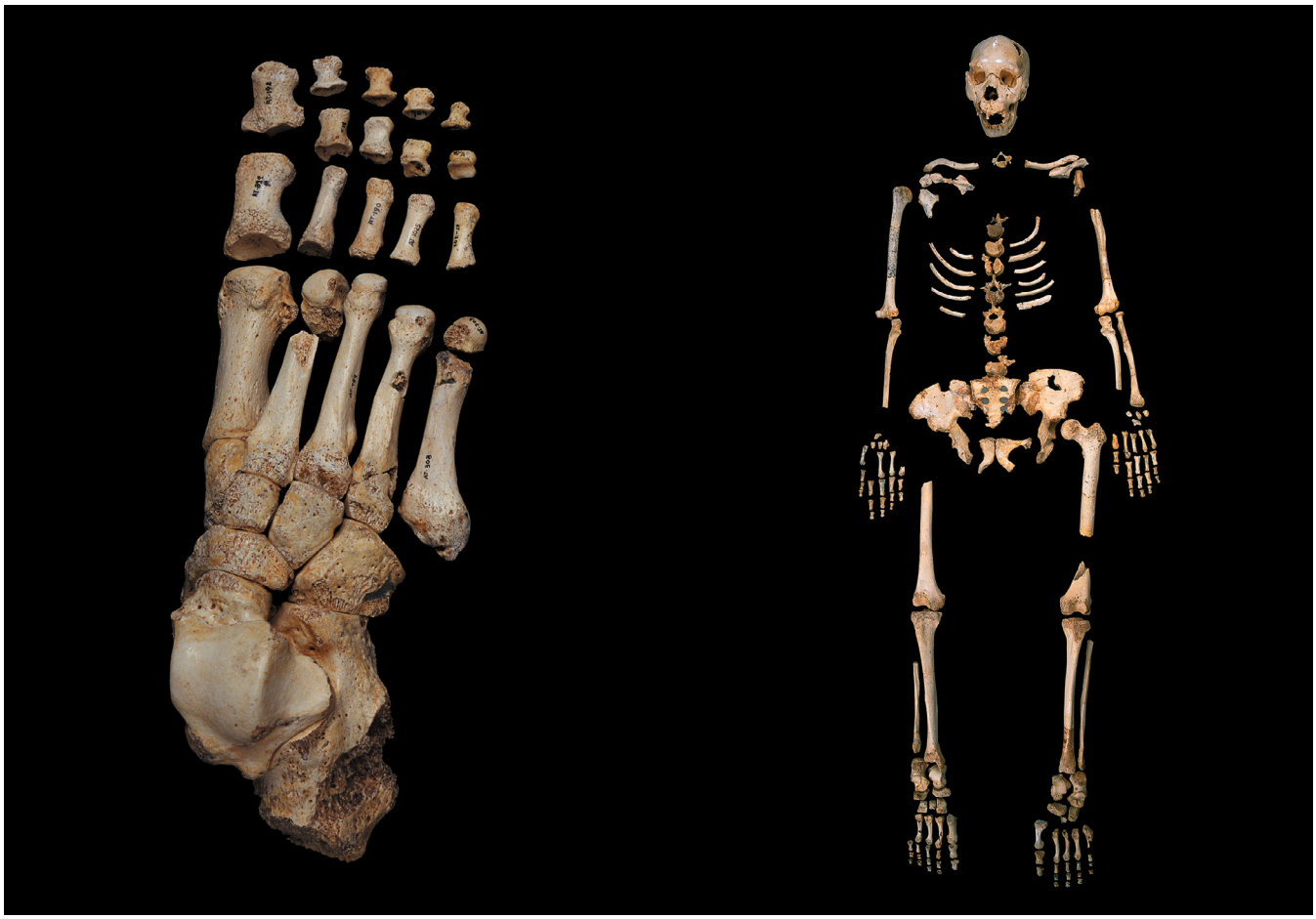

FIGURE 25 All regions of the human skeleton are represented in the Sima de los Huesos human fossil collection. On the left, the bones of the same foot. On the right, a skeleton composed of fossils of different individuals of the same size and stage of development.

latitude in which *H. erectus*/*ergaster* originated and lived. Thus, the slender-bodied biotype, adapted to lose heat easily, would be the primitive model within the genus Homo, while the wide bodies and shorter limbs of the Neanderthals would have appeared later in human evolution, as an adaptation to retain heat in the cold European environments. Until the discovery of *Elvis*, there was insufficient data from another human species with which to test these ideas. The dimensions of *Elvis* are much larger than those of H. sapiens males, especially in their transverse width (from side to side of the waist). This data implies that the body of the individual to which *Elvis* belonged was considerably wider than that of present-day human males. Therefore, the population of the Sima de los Huesos shared with the Neanderthals the presence of a wider body than that of present-day mankind. Thus, the results of the studies carried out on the fossils from the Sima de los Huesos show that the ancestors of the Neanderthals already had a wide body (Arsuaga et al., 1999, 2015). This novel view implied that, contrary to what was thought, the primitive morphotype in the genus

FIGURE 26 Lateral view of a cranium of *Ursus deningeri* from the Sima de los Huesos. It was nicknamed by the researchers as *Isidro*.

Homo is the broad body, which is present in *H. erectus/ergaster*, the Sima de los Huesos population and H. neanderthalensis. The narrow body of *H. sapiens* would be a peculiarity developed exclusively by our species.

FIGURE 27 Nuria García excavating a cranium of *Ursus deningeri* in the Sima de los Huesos.

One of the most notable aspects of the collection of human fossils recovered in the Sima de los Huesos until 1997 was the large number of remains corresponding to the limb skeleton (Carretero, García-González, et al., 2024, Carretero, Rodríguez, et al., 2024b, this volume; García-González et al., 2024, this volume; Rodríguez et al., 2024a, 2024b, this volume). The fossil record of human evolution is rich in teeth, jaws and crania, but relatively poor in the rest of the bones of the skeleton, especially in the fossil record of the genus *Homo* prior to the Neanderthals. After thirteen excavation campaigns, more than a thousand postcranial fossils had been recovered, corresponding to all regions of the skeleton (Gómez-Olivencia & Arsuaga, 2024a, 2024b, this volume; Pablos & Arsuaga, 2024a, 2024b, this volume), from the fragile phalanges of the hands and feet to the most resistant long bones of the extremities, such as the humeri and the femora (Figure 25). It was also found that all the bones of the skeleton were represented proportionally and there was no bias in the representation of the different skeletal regions. This information necessarily implied that complete human corpses had accumulated in the Sima de los Huesos and not isolated bones transported from somewhere else.

FIGURE 28 Hand ax discovered in 1998 in the level with human fossils of the Sima de los Huesos.

FIGURE 29 The hand ax from Sima de los Huesos. It was nicknamed by the researchers as *Excalibur*.

The study of this rich collection of the Sima de los Huesos allowed us to establish the height and body proportions of those people. Their height was similar to that of current human populations, but their trunk was much wider (Gómez-Olivencia & Arsuaga, 2024b, this volume),

FIGURE 30 Sima de los Huesos team showing the *Excalibur* hand ax on the day of its discovery in the 1998 field season. Juan Luis Arsuaga is in the center showing the hand ax. Clockwise from Juan Luis Arsuaga: Nuria García, Carlos Lorenzo, Alfonso Esquivel, Ignacio Martínez, Ana Gracia, José Miguel Carretero.

FIGURE 31 Ignacio Martínez excavating the Cranium 14 in the Sima de los Huesos in 2001.

which resulted in a larger body weight. On the other hand, it was also possible to study the difference in body size between women and men in the Sima de los Huesos and it was discovered that this difference was similar to that of current human populations (Arsuaga, Carretero, et al., 1997). Thus, an average male from Sima de los Huesos would been of around 170 cm tall with a body mass of around 90 kg. For its part, an average woman would be around 160 cm tall and have a body mass of around 75 kg.

In the 1999 campaign, a practically complete cranium of a bear specimen was found, of the species *Ursus deningeri* (Figure 26), which the researchers affectionately nicknamed Isidro in memory of the bear that appears on the coat of arms of the city of Madrid. In addition to this cranium, remains corresponding to more than 200 specimens of this species have been recovered in the Sima de los Huesos (García et al., 2024) (Figure 27). Researchers explain this unusual accumulation of bear remains at the site as a result of accidental falls over many centuries, with the Sima de los Huesos becoming a natural trap for bears that wintered in the adjacent Sala de los Cíclopes. The bear fossils appear both in the same stratum as the human fossils, mixed with them, and also in the upper stratum, in which there are no human fossils. Some human bones show isolated marks of bear teeth, which is interpreted to mean that a bear that fell into the Sima de los Huesos and survived for some time occasionally gnawed on one of the human bones that were already there.

In the 1998 campaign, the most surprising and enigmatic discovery made to date in the Sima de los Huesos took place (Figure 28). It is the only piece of industry found to date at the site, a striking biface carved from red quartzite, which takes on the color of a heart when wet with water (Figure 29). Intriguingly, the type of rock in which the biface is carved is not common in the Sierra de Atapuerca region and there are no known tools carved in that material among the hundreds of lithic pieces recovered in the nearby sites of the Trench of the Railway that are contemporaries of the Sima de los Huesos (Galería, and level 10 of Gran Dolina). The traceology studies that have been carried out have not been able to establish if the biface was used and for what purpose, since its surface is altered erasing any possible marks of its use. The presence of this biface at the site has been interpreted by many researchers as an offering, which would represent the oldest symbolic act known, and for this reason the researchers nicknamed it *Excalibur*, like King Arthur's magic sword (Figure 30).

The 20th century ended with great news for the Atapuerca sites and its team. In view of the great scientific value of the Sierra de Atapuerca, UNESCO granted it (on November 30, 2000) the status of World Heritage Site in consideration of its "Outstanding Universal Value." This marked the end of a prodigious decade in terms of discoveries, but there were still many fossils to recover and many important discoveries to make in the following years in the Sima de los Huesos.

1.4 | The NeverEnding story (2001–2024)

The 21st century debuted in the Sima de los Huesos with a discovery of great importance for the knowledge of the evolution of one of the most important traits of human behavior: solidarity with vulnerable people. In the 2001 campaign, an event took place that had not been repeated since the 1994 campaign, a very complete human cranium

FIGURE 32 Cranial fragments of Cranium 14.

FIGURE 33 Cranium 14 from Sima de los Huesos. It was nicknamed by the researchers as *Benjamina*.

FIGURE 34 Cranial fragments in situ in the Sima de los Huesos.

was discovered, Cranium 14 (Gracia et al., 2009). Its excavation was especially laborious because the cranium had fractured bones, although they were held together by the sediment, and in an extremely fragile state. In addition, it was located next to one of the walls of the Sima de los Huesos, which made its excavation even more difficult (Figure 31). When the cranium could finally be extracted from the sediment, it was taken to the laboratory where it was cleaned and reconstructed, as it was fractured into dozens of small fragments (Figure 32). Once reconstructed, it was possible to establish that it was a pre-adolescent girl whose cranial shape surprised the researchers, as it

FIGURE 35 Crania discovered in the Sima de los Huesos until 2012. Top row, from left to right: Cranium 11, Cranium 15, Cranium 4, Cranium 14, Cranium 6, Cranium 9, Cranium 17 and Cranium 5. Bottom row, from left to right: Cranium 1, Cranium 8, Cranium 2, Cranium 7, Cranium 10, Cranium 12, Cranium 13 and Cranium 3.

showed a straight forehead, instead of a receding one (Figure 33). The straight forehead is a specific feature of our species and was not expected in an individual of the Sima de los Huesos antiquity. In addition, other cranium of similar age at death is known in the Sima de los Huesos collection and none have a straight forehead. Upon closer examination, the researchers noticed that the cranium had other unusual features: its cranial vault and cranium base were severely deformed, and the cranium lacked the bilateral symmetry characteristic of all vertebrate crania. In-depth study of this enigmatic cranium revealed a touching story. The girl suffered a trauma, due to a blow or a bad posture, while she was still in her mother's womb. As a result, one of her cranial sutures, the left lambdoidal suture, fused before she was even born. The brain continued to grow, but the cranium could not grow harmoniously and became deformed. The deformation of the cranium also seriously affected the girl's face and most likely caused the child to suffer from delayed psychomotor skills. But despite the different appearance that her deformed face would give her, and her physical and psychological limitations, not only was the girl not rejected by the group but also she received the care and affection necessary to survive until she was 10 or 12 years old, like other children whose remains appear in the Sima de los Huesos (Gracia et al., 2009). This extraordinary story, which constitutes the oldest secure evidence of care for children with disabilities, moved researchers to nickname her *Benjamina*, which, in Hebrew (*Binyāmîn*), means "She of the right", in reference to the favorite daughter, the most beloved. This name is a tribute to the love of parents for their disabled children.

During the 10 years that followed *Benjamina*'s discovery, dozens of new cranial fragments were recovered (Figure 34) that made it possible to painstakingly reconstruct the crania of other individuals, up to a total of 20 (Pantoja-Pérez & Arsuaga, 2024, this volume). Among them, four very

FIGURE 36 Cranium 17 from Sima de los Huesos showing the two penetrating lesions in its frontal bone.

complete ones stand out (Figure 35): Cranium 9 (of an early teenager), 15 (of an elderly individual), 16 (of a late adolescent) and 17 (of a young adult). At the same time, much progress was made in understanding the stratigraphy of the site, which allowed the site to finally be solidly dated to between 430,000 and 300,000 years ago through the use of different radiometric techniques (Arsuaga et al., 2014). However, one of the most important questions still remained to be answered: How had the bodies of at least 29 people gotten to that remote place? Some authors proposed that the bodies could have been dragged there by water or mud from elsewhere, or that perhaps it was the lions (of which fossils in Sima de los Huesos) who transported them (Sala et al., 2014). However, these hypotheses were discarded as more and more data on the site became known. Finally, only two possible hypotheses remained. On the one hand, the accumulation of corpses could have had a fortuitous origin due to a succession of

accidents involving individuals wandering through the cave. On the other hand, an alternative hypothesis proposed that it had been other humans who had deliberately transported the bodies there. Although the hypothesis of successive accidents seems very unlikely, the truth is that the idea that Sima de los Huesos constitutes the first intentional accumulation of human corpses in history is an extraordinary statement that required finding extraordinary evidence to prove it. And this evidence came with Cranium 17 (Figure 36). This specimen presents a double penetrating trauma to the left side of its frontal bone (Sala et al., 2015). Surprisingly, the perimeters of both injuries have the same shape and length, which implies that they were produced by the impact of the same object and with a similar force. This double traumatic injury could not have occurred once the body was in the site, nor during the body's fall into the chasm since it is not possible to accidentally hit your head twice with the same object and with the same force. So, the injuries would have occurred before the body fell into the chasm and, since these are two fatal injuries, it is inevitable to conclude that the individual was dead before his body fell into the chasm. This interpretation rules out the possibility of casual accidents as the origin of the accumulation and supports the hypothesis of the intentional accumulation of corpses (Sala, Pantoja-Pérez, et al., 2024, Sala, Martínez, et al., 2024, this volume).

The extraordinary state of conservation of the fossils from the Sima de los Huesos and the favorable physicochemical conditions of the site led the researchers to conceive the possibility that there was still DNA left in some of them. First, it was tested with bear fossils from the same level as the human fossils, which ensured that they were of the same age and had had the same conservation conditions. The researchers managed to recover and sequence representative fragments of mitochondrial DNA from some specimens of *Ursus deningeri* (Valdiosera et al., 2006). This success opened the door to carrying out the test with some very fragmentary human remains and in 2014 it was possible to obtain and sequence mitochondrial DNA Its comparison with the other fossil humans for which the genomes were known (the Neanderthals and the Denisovans) yielded a surprising result. Anatomically, the fossils from Sima de los Huesos and Neanderthals show a clear phylogenetic affinity, especially in the morphology of the jaw (Quam et al., 2024) and dentition (Bermúdez de Castro et al., 2024a, 2024b), greater than that between Neanderthals and Denisovans, but, however, the mitochondrial DNA of the fossils from Sima de los Huesos presented greater resemblance with the Denisovans than with the Neanderthals (Meyer et al., 2014). This discrepancy between anatomical and genetic data allowed for several explanations, but to solve the problem it was necessary to obtain significant nuclear DNA sequences, something that was technically more difficult than obtaining mitochondrial DNA. Despite the difficulties, in 2015 it was possible to obtain and sequence significant fragments of nuclear DNA from two fossils from the Sima de los Huesos that corresponded to two different individuals (Meyer et al., 2016). The results coincided with the anatomical studies and showed a greater affinity between Neanderthals and the Sima de los Huesos than any of them with the Denisovans.

Another scientific challenge that has been possible to address with the fossils from the Sima de los Huesos has been the study of the origin and evolution of language. In the 1990s, research on the origin and evolution of language was focused, in the field of Paleoanthropology, on the comparative study of the anatomy of the basicranium and the hyoid bone to try to reconstruct the phonatory abilities of fossil human species. However, there was intense controversy about the value of these anatomical structures for inferring the sounds that humans of the past could produce. To make matters worse, the base of the cranium is a very fragile region, which most fossil crania have lost completely or partially, and only the hyoid bone of one Neanderthal specimen was known. So, it was not possible to study the basicranial anatomy and that of the hyoid bone in the same individual or, at least, in individuals from the same population. That situation changed with the discovery in the Sima de los Huesos of Cranium 5 (*Miguelón*), whose basicranium is perfectly preserved, and of two very complete hyoid bones. In no other site in the world, both anatomical regions are available from the same population. However, the study of these fossils led the research team to the conclusion that

FIGURE 37 Sima de los Huesos Team in the 2023 field season. Clockwise from left bottom: Nohemi Sala, Carlos Lorenzo, Juan Luis Arsuaga, Arantza Aramburu, Ignacio Martínez, Nuria García and Rolf Quam.

FIGURE 38 Juan Luis Arsuaga, on the left, explaining to the public the Pelvis 1 of the Sima de los Huesos at the Museum of Human Evolution in Burgos.

it was not possible to reach conclusive results on the phonatory abilities of fossil human species through detailed study of these anatomical regions (Martínez et al., 2013). For this reason, they decided to start an unprecedented line of research: try to establish the communicative abilities of the humans from the Sima de los Huesos by studying their hearing.

Humans not only differ from the primates closest to us in the anatomy of the larynx, which enables us to speak, we also do so in the anatomy and physiology of the ear. Our hearing is delicately adjusted to the sounds of speech, to which it shows great sensitivity. For its part, chimpanzees' ears are "tuned" to other sounds: those they usually use to communicate in the forest with their peers. So, in the auditory pattern of a fossil species, important keys can be found to understand the efficiency and complexity of its oral communication systems and determine whether it was more similar to that of chimpanzees or that of modern humanity.

The idea was good, but how to establish the hearing pattern of an individual who had died more than 430,000 years ago? To do this, we had an incredible collection of 30 middle ear bones and also the temporal bones of more than a dozen different individuals. Currently, there are biophysical models that simulate with complete fidelity the acoustic filtering process that takes place in our external and middle ear (Martínez et al., 2004). This acoustic filtering is responsible for the hearing differences between chimpanzees and modern humans. So, by knowing the acoustic filtering pattern of the people from Sima de los Huesos, we can determine if their hearing was more similar to that of chimpanzees or to that of our own species and, thus, determine the efficiency and complexity of their system. To apply the biophysical model that reconstructs acoustic filtering, it is necessary to have values of more than a dozen anatomical variables, both of the ossicles of the ear and the cavities of the external and middle ear. To do this, the temporal bones of nine specimens from the Sima de los Huesos were scanned tomographically and three-dimensional models that can be measured on the computer were constructed, from hundreds of high-resolution tomographic images (Conde-Valverde et al., 2024, this volume). Once the measurements were obtained and introduced into the model, the results indicated that the auditory and, therefore, communicative abilities of the humans from Sima de los Huesos were more similar to those of our species than to those of chimpanzees. This result indicates that those humans were able to use most of the vowel and consonant sounds that current humans use for their oral communication (Conde-Valverde et al., 2024, this volume).

2 | CONCLUSION

Four decades of systematic excavations at the Sima de los Huesos have provided the largest and best-preserved collection of human fossils on the planet. With them, studies have been carried out that have increased our knowledge of human evolution, in general, and that of the genus *Homo*, in particular. But the work is far from finished and the team of researchers estimates that more than 50% of the human remains, that accumulated there, have yet to be recovered (Figure 37). Without a doubt, these new fossils will allow us to carry out new research that will further expand our knowledge, but the scientific potential of the current collection of human fossils is not exhausted and numerous investigations are currently underway on different aspects of the biology of those humans.

Fortunately, the great scientific adventure that the excavation of the Sima de los Huesos entailed has been recorded in cinematographic images to the satisfaction of all scholars and lovers of Human Evolution. Human fossils also constitute a treasure of great emotional value, and it is only right that the public has the opportunity to visit and admire them. For this purpose, the spectacular Museum of Human Evolution was built in the city of Burgos, which today is the home of these venerable fossils. There, everyone is welcome to come and personally meet *Agamemnon, Miguelón, Elvis, Excalibur, Benjamina*... and the rest of the others (Figure 38).

AUTHOR CONTRIBUTIONS

Juan-Luis Arsuaga: Conceptualization; investigation; funding acquisition; writing – original draft; writing – review and editing. **Ignacio Martínez:** Conceptualization;

investigation; writing – original draft; writing – review and editing. **Ana Gracia-Téllez:** Conceptualization; investigation; writing – original draft; writing – review and editing. **José-Miguel Carretero:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Alfonso Esquivel:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Nuria García:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Carlos Lorenzo:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Rolf Quam:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Arantza Aramburu:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Nohemi Sala:** Conceptualization; investigation; writing – original draft; writing – review and editing. **Javier Trueba:** Visualization; writing – original draft; writing – review and editing; funding acquisition.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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